THREE DIMENSIONAL FINITE ELEMENT ANALYSIS OF STRESS DISTRIBUTION AROUND IMPLANT WITH STRAIGHT AND ANGLED ABUTMENTS IN DIFFERENT BONE QUALITIES.

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CERTIFICATE

This is to certify that this dissertation entitled **"THREE DIMENSIONAL FINITE ELEMENT ANALYSIS OF STRESS DISTRIBUTION AROUND IMPLANT WITH STRAIGHT AND ANGLED ABUTMENTS IN DIFFERENT BONE QUALITIES."** is a genuine work done by ***Dr. MAHESH B*** under my guidance during her post graduate study period between 2009-2012.

This Dissertation is submitted to THE TAMILNADU Dr. M.G.R MEDICAL UNIVERSTY, in partial fulfillment for the degree of **MASTER OF DENTAL SURGERY IN PROSTHETIC DENTISTRY INCLUDING CROWN AND BRIDGE AND IMPLANTOLOGY - BRANCH I.** It has not been submitted (partial or full) for the award of any other degree or diploma.

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ABSTRACT

TITLE:*Three dimensional finite element analysis of stress distribution around implant with straight and angled abutments in different bone qualities.*

AIM:*The aim of this study was to compare the stress distribution in different bone qualities of D1, D2, D3 & D4 with straight and angled abutments using Three Dimensional Finite Element analysis.*

MATERIALS AND METHODS:*A three dimensional finite element model of the premaxilla region and a solid 4.3 x 10 mm implant with a straight abutment (M1) and an angled abutment (M2) was done. Four distinctly different bone qualities of D1 ,D2 ,D3 & D4 were made. Simulated occlusal load of 178 N was applied at the centre of incisal edge along the long axis of each abutment. The maximum equivalent von Misses stress values around the implants were recorded.*

RESULTS:*The distribution of stresses changed considerably with abutment angulation. As angulation increased from 0^0 to 15^0 the concentration of von Mises stress shifted to the cortical layer of bone on the facial side of the fixture. In D1, D2, D3 & D4 bone qualities the highest von Mises stress values were obtained at the crestal region of implant. The maximum von Mises stress of 20.832 was recorded in D4 cortical bone on the buccal side of angled abutment.*

CONCLUSION: *The high stresses induced through preangled abutments at the cervical zone of the implant due to forces and moments could be a dominant factor that may aggravate the peri implant bone loss or may change the existing periimplantitis direction.*

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Introduction

INTRODUCTION

Dental implants have been proven to be an effective way of restoring the masticatory ability of completely or partially edentulous patients. The desired position of the artificial teethis determined by esthetic and functional requirements. Sufficient amount of bone for implant placement is an essential pre requisite for the long term success in oral implant therapy. The quantity of alveolar bone decreases after periodontal disease or after extraction, causing bone loss in both horizontal and vertical direction.

Lack of horizontal bone volume always result in exposure of implant surface, decreased bone- implant interface and finally implant failure. Lack of bone volume is more common in the anterior maxilla. The long term prognosis for implants in the maxilla is less secure than that of edentulous mandible[4]. Following tooth extraction in the anterior part of the maxilla horizontal bone resorption is almost twice as pronounced as vertical resorption[30].

This can be managed either by surgical correction or by positioning the implant in the area with the greatest available bone with the intention of correcting the implant alignment at the time of implant restoration. This is made possible, in carefully planned cases, using angled implant abutments.

Eger et al and Sethi et al concluded that angled abutments may be considered a suitable restorative option when implants are not placed in ideal axial positions[15,14]. The successful osseo integration of implant depends not only on the bone quantity but also on the bone quality[52].The classification scheme for bone quality proposed by Lekholm and Zarb[28] has been accepted by clinicians and investigators as standard in evaluating patients for implant placement. In this system, the sites are categorized in 1 to 4 groups on the basis of jawbone quality.

In Type 1 (D1) bone quality, the entire jaw is comprised of homogenous compact bone.

In Type 2 (D2) bone quality, a thick layer (2 mm) of compact bone surrounds a core of dense trabecular bone.

In Type 3 (D3) bone quality, a thin layer (1 mm) of cortical bone surrounds a core of dense trabecular bone of favorable strength.

In Type 4 (D4) bone quality, a thin layer (1 mm) of cortical bone surrounds a core of low-density trabecular bone.

Implant manufacturers have introduced preangled abutments as a prosthetic option for dentitions that are otherwise difficult to restore because of implant locationor angulation. The angulation of these abutments varies from 15^0 to 35^0. Clinical comparative studies of implant with straight abutments and angled abutments showed that the bone loss or the survival rate of angled abutments were not significantly different from straight abutment[10,14,20,46] .However the Strain gauge measurements and Photoelasticmodels of Brosh et al[12]and the finite element analyses of Canay et al [9]and Clell and et al[7]revealed that angled abutment were subjected to higher stress values around the cervical region than those observed for straight abutment.

Few investigators have studied the unavoidable situation of placing and loading implants at an angulation in the anterior maxilla, but they did not consider the variation in bone qualities[5,7] which may influence the stress distribution around the implant with angled abutments. The purpose of the present studyis to compare the stress distribution in various bone qualities of D1,D2,D3 and D4 with straight and angled abutments using three dimensional finite element analysis.

Aim of the Study

AIM

The aim of this study was to compare the stress distribution in different bone qualities of D1,D2,D3 &D4 with straight and angled abutments using three dimensional finite element analysis.

Review of Literature

REVIEW OF LITERATURE

Douglas Allen Atwood (1962)[1]stated that resorption of residual ridge is a complex biophysical process. When force within certain physiologic limits is applied to living bone, that force, whether compressive, tensile, or shearing, brings about by some unknown mechanism the remodeling of the bone through a combination of bone resorption and bone formation.

Bone resorption of residual ridges is a common occurrence after the extraction of teeth. Both the total amount of bone loss and the rate of resorption varied among different patients. In addition, the rate of resorptionvaried for a given patient at different times.

Bo Rangert et al (1989)[2]stated that Two main types of loading of the implants should be considered: *(1)* axial force and *(2)* bending force. Axial forces are more favorable, because they distribute stress more evenly while bending forces exert (unfavorable) stress gradients on the implant. If loading of the fixtures mainly consists of bending moments, the mechanical load on the system may be excessive.

For well-integrated fixtures in bone of good quality, the weakest point in the system will be the gold or abutment screw, which should be regarded as a safety feature

Nancy .L. Clelland and Amos Gilat (1992)[3]compared the stress production characteristics of five abutment angulations for a 3.75 x 10-mm Branemark implant system. Each 4-mm abutment of 0^0,15^0, *25^0*, and 35^0 angulation was assembled on the fixture, subjected to 178N load, and viewed with a circular polariscope. The authors concluded that stress distribution is more favorable forabutments of less angulation. All of the five abutment angulations investigated produced strains at the location of the rosettes that were within the physiological zone for bone and *h*igher stresses and strains can beexpected closer to the fixture.

Charles .A. Babbush, Mari Shimura (1993)[4]evaluated patients who were reconstructed with the IMZ system, which consists of a cylindrical implant with anintramobile element for stress relief. It is placed through a two-stage surgical procedure resulting in osteointegration. They concluded that

Implants in the maxilla had a lower survival rate than implants in the mandible.

Nancy L. Clelland et al (1993)[5]conducted a study to determine the effect of abutment angulation on the stress field near a specific dental implant. Zero-degree, 15-degree, and 20-degee abutments were assembled on each of the six 3.8× 10-mm Steri-Oss implants , subjected to 178 N load, and viewed with a circular polariscope. As the abutment angle changed from 0 degrees to 20 degrees, compressive stress nearly doubled, and the changes were statistically significant. Tensile stress increased with an increase in abutment angulation, but the increase was only statistically significant between 0 and 15 or 20 degrees.

Nancy L. Clelland et al (1995)[6]Analyzed the stresses and strains produced by an abutment system of three abutment angulations by three-dimensional finite element model of the maxilla. A simulated occlusal load of 178 N was applied along the long axis of 0^0 ,15^0 and 20^0 abutments. Peak stresses were located in the cortical bone, and the magnitude of these stresses increased with an increase in the abutment angulation. These maximum stress values were within the physiological parameters described for animals with one exception. Peak compressive stress for the 20^O abutment was slightly above this physiological zone, and this result suggests a need to evaluate greater abutment angulations. Although strains were primarily situated in the cancellous bone for all three cases, a more facial location was observed for the 15^O and 20^Oangles.

Renato Celletti,Carneas.H. Pameijer (1995)[7] studied the transmission of masticatory forces on the bone by the use of preangled abutments on implants. Nineteen endosseous implants were placed in two subhuman primates. Then waiting period of six months were given to allow osseointegration. The implants were fitted with Straight non segmented abutment sand preangulated abutments of 25 and 35degrees. Clinical and histological evaluation were done. His tologic evaluation revealed that after 1 year the implants showed complete osseointegration. Implants whether restored with straight or preangled abutments, had no adverse effect on the surrounding bone. Loss of components were caused by mechanical failure of abutment screws and did not affect the integrity of the implants. The results of this study indicate that osseointegrated implants placed at unfavorable angles can be fitted with preangled abutments without compromising esthetics and function.

G.Papavasiliou,P.Kamposiora,S.Bayne,D. A. Felton(1996)[8]investigated clinical simulations involving single implants that were capable of creating excessive stress at bone implant interface that exceeded elastic limit of bone. Changing the veneering material on the prosthesis had no significant effect on the stress levels or distribution at the bone-implant interface. Oblique loads produced great increase over axial loading for stress levels and distributions. Under axial loading, high resolved stresses were produced on the occlusal third of the superstructure and low stresses were distributed to the bone. The highest stresses were concentrated in the cortical bone. Stresses under oblique loading were approximately10 times greater than under axial loading.

Canay .S.etal (1996)[9]Analyzed the distribution of stress around implants placed in the first molar region of the mandible biomechanically in a two-dimensional mathematical model and found no measurable differences in stress values and contours when a horizontal load was applied to the vertical and angled implants. However, with the vertical loading, the compressive stress values were five times higher around the cervical region of the angled implant than around the same area in the vertical implant.

Thomas .J .Balshi et al(1997)[10] observed that from 3 year survival rates study showed good preliminary results for angulated abutments compared to standard straight abutments .Total percentage of implant loss in relation to bone quality –Type- I, II, III, IV are the same as in standard abutments. The study indicated that angulated abutments should be comparable to standard straight abutments as a predictable modality in prosthetic rehabilitation.

RoxanaStegaroiu et al (1998)[11] assessed stress in bone around titanium implants using three treatment designs for a partially edentulous mandible, under axial (AX), buccolingual (BL), or mesiodistal (MD) loads.

Model 1: Three implants supporting three connected crowns (M1) Model 2: Two implants supporting a cantilever prosthesis (M2) Model 3: Two implants supporting a conventional FPD (M3)For each of these loads, highest stress was calculated in the model with a cantilever prosthesis supported by two implants (M2). Less stress was found in the model with a conventional fixed partial denture on two implants (M3), and lowest stress was calculated in the model with three connected crowns supported by three implants (M1). When BL load was applied to conventional fixed partial denture on two implants(M3), cortical bone stress was high, comparable to that calculated for M2 under the same load.

Tamar Brosh, Raphael Pilo, and David Sudai (1998)[12]Studied the influence of abutment angulation on strains and stresses along the implant bone interface by using strain gauges attached to implants embedded in a medium simulating bone and compared the results with photoelastic method . Strain guage measurement showed that when the abutment angle was increased from 0 to 15 degrees, 300% higher compressive strains were measured, compared with the straight abutment. They concluded that identical vertical loads applied on preangled abutments produced higher stresses at the coronal zone of an implant compared with the straight abutment.

Graziono.D. Giglio(1999)[13]described the process of selecting on abutment. He stated that involves evaluating the position, angulation, interocclusal space, and tissue height of a given implant. An angulation discrepancy greater than 15 degrees usually requires an angulated, cementable, or custom abutment. When using acementable restoration, the angulation is not as critical since there is no screw-access opening. Angulated abutment replicas (angulation guides) are commercially available in varying angulations and tissue heights to help select the appropriate angulated abutment.

AshokSethi, ThomasKaus, Peter Sochor (2000)[14]presented preliminary results of the clinical long-term behavior of implants restored using a broad range of angulated abutments. These were observed over a period of up to 96 months, with a mean observation time of 28.8 months. With a certainty of 95%, an estimated mean survival rate better than 98.6% after a 5-year observation period was calculated.

The results of this study demonstrated that there is no difference in the survival of implants based on the use of angulated abutments ranging from 0 to 45 degrees and they can be used without compromising the long-term survival of implants.

Dorothy E. Eger- (2000)[15]compared the survival of straight and angled abutments and noted that after one year, they found no statistically significant differences with respect to probingdepths, gingival inflammation or attachment levels around straight or angled abutments. A comparison of clinical and demographic variables, evaluated for implants restored with angled and standard abutments, yielded no significant differences for any parameter at any time period. They suggested that end osseous implants placed at unfavorable angles may be restored with angled abutments without compromise of function or esthetics.

John. B. Brunski(2000)[16]Stated that all oral and maxillofacial implants are meant to support forces in vivo, so it is obvious that biomechanics plays a major role in implant design. For lateral bite forces in the normal human dentition, the data are less definitive. All implants will be exposed to intra oral forces and moments and loads will be transmitted to interfacial tissues. In the incisal region, the direction of maximum incisal bite force is about 12 degrees to the frontal plane, which suggests that the lateral components of force on an anterior implant could be appreciable. They also stated that for Biomechanical Models for Predicting Implant Loading 3-dimensional FEA models are more advantageous than strain-gauged abutments and photoelastic models .

David .G. Gratton et al (2001)[17] Investigated dental implant screw joint micromotion and dynamic fatigue as a function of varied preload torque applied to abutment screws when tested under simulated clinical loading. The results of the study revealed that under the loading parameters of this study, no measurable fatigue of the implant– abutment interface occurred. However, dental implant screw joints tightened to lower preload values exhibited significantly greater micromotion at the implant–abutment interface.

Jian-Ping Geng et al (2001)[18]Reviewed the current status of FEA applications in implant dentistry and discusses findings from FEA studies in relation to the bone–implant interface, the implant–prosthesis connection, and multiple-implant prostheses They stated that key factor for the success or failure of a dental implant is the manner in which stresses are transferred to the surrounding bone. Factors that influence load transfer at the bone–implant interface include the type of loading, implant and prosthesis material properties, implant length and diameter, implant shape, structure of the implant surface, nature of the bone–implant interface, and the quality and quantity of the surrounding bone can be studied by FEA.

Estevam B. et al (2002)[19]Compared the Stress Distribution between Angled And Vertical Implants and saw that Stresses in the angled implant were higher than in vertical model. The larger differences in stresses were for vertical loading, reaching 25%for peak compressive stresses. Much higher stress values as expected occurred under horizontal loading, for both designs. It should be noted that in normal function, during mastication, the vertical components of the loading are significantly higher than the horizontal components.

Ashok sethi et al (2002)[20]Described the evolution of the concept of selecting the abutment at first-stage surgery and presents clinical data accumulated over 14 years of the use of this concept with angulated abutments. Good esthetic and functional outcomes were achieved by the use of conventional cement-retained restorations made possible by parallel and aligned abutments. Over 10 years, the angulation had no effect on the probability of survival of the implants.

Tada.S.et al (2003)[21] Performed a 3-dimensional finite element analysis to evaluate the influence of implant type and length, as well as that of bone quality, on the stress/strain in bone and implant. Axial and buccolingual forces were applied to the occlusal node at the center of the abutment. Regardless of load direction, maximum equivalent stress/strain in bone increased with a decrease in cancellous bone density. Under axial load, especially in the low-density bone models, maximum equivalent strain in cancellous bone was lower with the screw-type implant than with the cylinder- type implant.

Murat Sutpideler.M, etal (2004)[22] conducted finite element analysis to determine the stress in the supporting bone when implants were arranged in either a straight-line or an offset configuration and assessed the effects of axial and nonaxial loading and changes in prosthesis height **.**Vertical loading of an implant-supported prosthesis produced the lowest stress to the supporting bone. Changes in the angle of force application resulted in greater stress to supporting bone. Reduction in prosthesis height or use of an offset implant location for the middle implant reduced stress, but the reduction did not compensate for the increase found with off-axis loading.

Murat Cehreli et al (2004)[23]Compared stress and strain magnitudes of butt-joint and internal-cone oral implants in a bone stimulant through photoelastic and strain-gauge analysis and found out that Butt-joint and internal-cone oral implants have similar force distribution characteristics.

They concluded that the implant–abutment mating design is not a decisive factor affecting stress and strain magnitudes in a bone simulant.

Murat cavitCehreli et al (2004)[24]Compared force transmission behaviors of one-piece (1-P) and two-piece (2-P) morse-taper oral implants by three-dimensional finite element analysis. Von Mises stresses in the implant, principal stresses, and displacements in the resin were the same for both designs under vertical loading. Under oblique loading, principal stresses and displacement values in the resin were the same, but the magnitudes of von Mises stresses were higher in the 2-piece implants They concluded that 2-piece implants experience higher mechanical stress under oblique loading.

Lucie Himmlova,T(2004)[25] stated that an increase in the implant diameter decreased the maximum von Mises equivalent stress around the implant neck more than an increase in the implant length, as a result of a more favorable distribution of the simulated masticatory forces applied in this study.

Eriko Kitamura et al (2004)[26] performed a three-dimensional finite element analysis of the influence of marginal bone resorption amount and shape on stress in the bone and implant was investigated. The results of this analysis suggest that a certain amount of conical resorption may be the result of biomechanical adaptation of bone to stress. However, as bone resorption progresses, the increasing stresses in the cancellous bone and implant under lateral load may result in implant failure.

E Kitamura et al (2005)[27]performed a three-dimensional finite element analysis to compare the bone stresses in a non-resorption model with those in four models with bone resorption of two depths (1·3 and 2·6 mm) and types (horizontal resorption and angular defects). Axial and bucco-lingual forces were separately applied to the center of the superstructure and the maximum equivalent stress was calculated. The main tendencies of bone stress (highest stress concentration around implant neck, higher stresses under bucco-lingual than axial load, as well as in the cortical than cancellous bone) were the same in the non-resorption and resorption models. Bone stress distributions were similar in the non-resorption and horizontal resorption models, but differed from those in the angular defect models. Moreover, the changes of the bone stress values with resorption depth differed for the two resorption types. Thus, in FEA, accurate simulation of the marginal bone shape in the implant neck region is advisable.

M. Sevimay et al (2005)[28]studied the effect of 4 different bone qualities on stress distribution in an implant-supported crown, using 3-Dfinite element (FE) analysis and observed that von Mises stresses in D3 and D4 bone qualities reached the highest values at the neck of the implant and were distributed locally. A more homogenous stress distribution was seen in the entire bone for bone groups D1 and D2, and a similar stress distribution was observed. Because the trabecular bone was weaker and less resistant to deformation than the other bone qualities modeled, the stress magnitudes were greatest for D3 and D4bone.

DING Xi et al (2005) [29] Applied three-dimensional finite element method to analyze the influence of various angled abutments on the distribution of the stress and strain in the implant-bone interface. Results showed that Von Mises stress occurred predominantly in the cortical bone layer-on the neck of implants. There was an increase occurred in the magnitude of stress and strain in the implant-bone interface as the abutment angulation increased. It increased obviously when the implant was connected by 30° abutment.

S. Jivraj ,W. Chee and P. Corrado(2006) [30] describes about the treatment plan in edentulous maxilla and stated that upon consideration of bone quantity, bone quality, resorptive patterns and maxilla mandibular relationship it usually becomes apparent that the actual amount of bone available for placement of implants in the maxilla may not only be limited but may also be present in areas remote from the original site of the natural teeth. In the pre maxilla the tooth position may be much further forward than the implant position and this may pose certain biomechanical disadvantages. So following the same prosthetic concepts forthe maxilla as existed in the mandible is notfeasible. The long term prognosis for implants in the maxilla is less secure than that of the edentulous mandible. In the edentulous maxilla type 3 or type 4 bone quality is often found. This quality of bone often dictates over engineering at time of implant placement.

Chun H.J. et al (2006)[31]investigatedthe effect of abutment type on stress distribution in bone under vertical and inclined loads by FEA with contact friction interface between abutments and three type implant system- one piece implant, internal hex and external hex. Maximum von Mises Stress occurred at the region of compact bone adjacent to the first implant microthead of all implant system with different abutments for both vertical and inclined loading. It was concluded that the abutment type has significant influence on stress distribution in bone because of different load transfer mechanism and difference in size of contact area between the abutment and the implant.

Flemming Isidor et al (2006)[32]reviewed the relationship between forces on oral implants and the surrounding bone. Occlusal forces affect an oral implant and the surrounding bone. Bones carrying mechanical loads adapt their strength to the load applied on it by bone modeling/remodeling. This also applies to bone surrounding an oral implant. The response to an increased mechanical stress below a certain threshold will be a strengthening of the bone by increasing the bone density or apposition of bone. On the other hand, fatigue micro-damage resulting in bone resorption may be the result of mechanical stress beyond this threshold In clinical studies an association between the loading conditions and marginal bone loss around oral implants or complete loss of osseointegration has been stated, but a causative relationship has not been shown.

Xavier E Zaab (2007)[33]measured and compared the strain distribution on the bone around an implant in the anterior maxilla using different abutments by means of finite element analysis. The greatest strain was found on the cancellous bone, adjacent to the 3 most apical microthreads on the palatal side of the implant where tensile forces were created.

The same strain distribution was observed around both the straight and angled abutments. The model predicted a 15% higher maximum bone strain for the straight abutment compared with the angled abutment

G. Dubois, M. Daas A.S. Bonnet , P. Lipinski (2007)[34]studied the complex behaviour of an upper lateral incisor restoration using an angled abutment, and a mechanical analysis of the abutment bearing capacity was firstly carried out by Finite Element Analysis . The authors concluded that the abutment studied could safely be used, in the case of an upper lateral incisor restoration, for a range of external forces included between 0 and 280 N. No yielding was observed in this situation. However, if this angled abutment was used for a molar restoration, a risk of damage would exist as the forces applied may exceed 300 N because it generated bending stresses inside bone and implant.

Jose Henrique Rubo, Edson Antonio CapelloSouza(2008)[35]Studied the stress distribution in bone adjacent to dental implants by means of FEA. They stated that the load transfer is dependent upon the occlusal loads, implant shape and size, biomaterial properties, density of bone, and nature of the interface. The presence of a stiffer cancellous bone has the benefit of reducing the stress where it reaches its peak, namely the cervical area around the terminal abutment. At the same time, the stress in cancellous bone somehow increases, balancing the stress distribution. The findings of this study have shown that varying the height of the abutments will have a different effect on bone around implants.

Kao.H.C etal(2008)[36]investigated the micromotion between the implant and surrounding bone caused by the use of an angled abutment for an immediately loaded single dental implant located in the anterior maxilla. The micromotion between the bone-implant interfaces was calculated using ANSYS software. The micromotion values for 15-degree and 25-degree angled abutments were 119% and 134%, respectively, compared to the corresponding values for straight abutments. Compared to straight abutments, the 25-degree abutments resulted in increased maximum von Mises stresses to a level of 18%.Most of the stresses were concentrated within the cortical bone around the neck of the implants. The authors concluded that , abutment angulation up to 25 degrees can increase the stress in the peri-implant bone by 18% and the micromotion level by 30%.

Baggi L et al (2008)[37]analysed the influence of implant diameter and length on stress distribution and to analyze overload risk of clinically evidenced crestalbone loss at the implant neck in mandibular and maxillary molar periimplant regions. Maximum stress areas were numerically located at the implant neck, and possible overloading could occur in compression in compact bone (due to lateral components of the occlusal load) and in tension at the interface between cortical and trabecular bone (due to vertical intrusive loading components). Stress values and concentration areas decreased for cortical bone when implant diameter increased, whereas more effective stress distributions for cancellous bone were experienced with increasing implant length. For implants with comparable diameter and length, compressive stress values at cortical bone were reduced when low crestal bone loss was considered.

Quaresma S.E. et al (2008) [38] evaluated the influence of two commercially available dental implant systems on stress distribution in the prosthesis, abutment, implant, and supporting alveolar bone under simulated occlusal forces, employing a finite element analysis. The stepped cylinder implant connected to a screw-retained, internal hexagonal abutment produces greater stresses on the alveolar bone and prosthesis and lower stresses on the abutment complex. In contrast, the conical implant connected to a solid, internal, conical abutment furnishes lower stresses on the alveolar bone and prosthesis and greater stresses on the abutment.

Georges Tawil (2008) [39]Reported that the stability of peri implant tissue is a balance between functional forces and reaction of supporting structures. Bone remodeling can be a possitive expression in response to mechanical stimulation. He stated that increased marginal bone loss can be either due to adaptation of function or due to increased occlusal overload.

Lin CL et al(2008)[40]studied the biomechanical response of implant system placed in the maxillary posterior region under various conditions of angulation, bone density and loading under finite element analysis. The result data for maximum von Mises stress for angled abutment was more than the straignt one. They also noted that implant and cortical bone strain was higher for an angled abutment of 20° than that for straight abutments and that bone strain increased as bone density decreased.

Golvani. E. Salvi (2009)[41] appraised the impact of mechanical and technical risk factors on implant-supported reconstruction by comparing the literature reviews and articles. The presence of angled or angulated abutments was not associated with increased mechanical or technical risks for implant-supported fixed dental prosthesis. The type of retention, the presence of angled abutments, the crown-implant ratio, and the number of implants supporting fixed dental prosthesis were not associated with increased mechanical or technical complications. None of the mechanical or technical risk factors had an impact on implant survival and success rates.

Chun-Li Lin et al (2009)[42]Investigated the interaction of implant position, implant abutment connection and loading condition influencing boneloss of an implant placed in the maxilla using finite element analysis. It was found that buccal site suffered the most bone loss around the implant, followed by distal, lingual and mesial sites. The implant position primarily influenced bone loss and it was found most obviously at the buccal site. Abutments of internal engagement with or without taper-fit did not affect the bone loss in the surrounding bone.

Ting Wua et al (2010)[43] Studied the biomechanical behavior of Computer-aided design/computer-aided manufacturing (CAD/CAM) custom abutments. Simulation results indicated that there was no distinct difference in the stress distribution and magnitude of implant-bone interface and screw using the custom or the conventional angled abutment.

Takeshi Takahashi et al (2010)[44]performed Three-dimensional finite element analysis to clarify differences in stress in peri-implant cortical bone between 6implants and 4 implants with change in inclination angle based on the All-on-4 Concept. They found that stress was concentrated around the posterior-most implant and the stress increased with 4 implants and increase in angulation. The use of 4 implants or inclined implants increased stress on peri-implant cortical bone. However, when used in conjunction with ashort cantilever, inclined implants decreased stress on peri-implant cortical bone.

Chun.yeoHa etal (2011)[45] studied the influence of abutment angulation on screw loosening of implants in the anterior maxilla. They found that the angled abutment group showed significantly higher removal torque values (RTV's) than straight abutments in external hex implants. However no significant difference in RTV was found among abutments in internal hex implants.

John Cavallaro, Jr. and Gary Greenstein (2011)[46] searched the dental literature for clinical trials that appraised the survival rate and complications (biological and technical) associated with pros-theses that are supported by angled abutments. The results of photoelastic stress assessments, finite element analysis and strain-gauge studies indicated that increased abutment angulations result in the placement of a greater amount of stress on prostheses and the surrounding bone than that associated with straight abutments. However, survival studies did not demonstrate a significant decrease of prostheses' longevity associated with angled abutments. Furthermore, there was no additional bone loss adjacent to implants that supported angled abutments compared with straight abutments, and angled abutments did not manifest an increased incidence of screw loosening. On the basis of the available data in literature, the authors concluded that angled abutments result in increased stress on the implants and adjacent bone. These increased stresses usually are within physiological tolerances.

Use of angled abutments has not decreased the survival rate of implants or prostheses in comparison with that of straight abutments, nor has the use of angled abutments resulted in an increased amount of bone loss.

Istibrak Hassan etal (2011)[47]investigated the influence of abutment design on bone resorption around immediately loaded and osseointegrated implants and found significant difference between non and submerged implants with angled abutment and between the submerged implants with straight and angled abutments. No significant difference were observed between non and submerged implants with straight abutments and between non submerged implants with straight and angled abutments. They concluded that bone resorption around dental implants is influenced by the abutment design and implantation protocol.

Ellakwa , Raj, Deeb. S. ,Ronaghi. G(2011)[48] Performed an in vitro study to assess the effect of three implant abutment angulations and three core thicknesses on the fracture resistance of overlaying computer-aided manufacturing (CAM) milled zirconia single crowns. Implant abutment angulations significantly reduced the fracture resistance of overlaying CAM-milled zirconia single crowns. The fracture loads of crowns cemented onto abutment preparations with a 30° angulation were the lowest of the groups tested. Reducing the core thickness from 0.8 mm to 0.4 mm did not affect the fracture resistance of overlaying CAM-milled zirconia single crowns.

JianpingGeng, W eiqi Yan, WeiXu[49] Application of the Finite Element Method in Implant Dentistry- Zhejiang University Press, Hangzhou and Springer-2008

Materials And Methods

MATERIALS AND METHODS

A three dimensional finite element model of premaxilla was created using a computerized tomography image. The scanned image was entered into a computer software program. Cross-sections were reassembled to get the three dimensional model of the premaxilla. Four distinctly different bone qualities of D1,D2,D3&D4 were made. A solid 4.3 mm x 10 mm screw type commercially pure titanium implant (Nobel Biocare, Goteborg, Sweden) with a straight abutment and an angled abutment was placed in the central incisor region. Three dimensional finite element model were constructed for the following configurations.

M1- an implant with astraight abutment(0^0).

M2- animplant with an angledabutment (15^0).

Each of these implants were placed in four premaxilla models of distinctly different bone qualities D1,D2,D3 and D4 respectively.

Abutments have a basediameter equal to implant diameter of 4.3 mm with occlusal taper. Apart from the different angulations the 7-mm abutments were identical.

Finite element models were simulated using Pro-engineering wild fire software (Parametric Technology Corp Needham MA USA).

The analysiswas performed using the software ANSYS Workbench 10.0.The models were processed in ANSYS to generate a meshed structure(Figures -1,2,3,4). Meshing divides the entire model into smaller elements which are interconnected at specific joints called nodes. The numberof elements and nodes used for each model is shown in Table I.

In the current study, the materials used for the models were presumedto be isotropic and the osseointegration of implant was accepted as 100%. The material properties were determined from values obtained fromthe literature[51](Table II) .A simulated occlusal load of178 N was applied at the centre of incisal edge along the long axis of each abutment (Figures- 5,6) . The amount of the load selected was based on the published average biting forces for incisor [33,7,50]. The applied forces were static.The maximum equivalent von Mises stress values around the implants were recorded .

The von Mises stresses are most commonly reported in finiteelement analysis studies to summarize the overall stress stateat a point . All materials were presumed to be linear, elastic, homogenous, and isotropic. Most Finite Element analysis studies in the literature have modeled cortical and cancellous bone to be homogeneous and isotropic[28,7].

BASIC CONCEPT OF FINITE ELEMENT ANALYSIS

Finite element analysis (FEA)was initially developed in the early 1960s to solve structural problems in the aerospace industry. In 1977, Weinstein was the first to use FEA in implant dentistry. Subsequently, FEA was rapidly applied in many aspects of implant dentistry [18,49].

FEA is a technique for obtaining a solution to a complex mechanical problem by dividing the problem domain into a collection of much smaller and simpler domains (elements) where field variables can be interpolated using shape functions.

FEA is a method whereby, instead of seeking a solution function for the entire domain, it formulates solution functions for each finite element and combines them properly to obtain a solution to the whole body. The finite element method provides a unique way of determining stress and displacements because of its ability to model geometrically complex structures. A computer simulated model is analysed to a numerical and graphical solution.In the finite element method the complex structure is divided in to smaller sub divisions called elements. The elements are interconnected at specific joints called nodes.

The whole collection of elements and nodes is called a mesh. A mesh is needed in FEA to divide the whole domain into small elements.

Meshing divides the entire model in to smaller elements.(Figure:4).With the incorporation of mechanical properties the structure simulate the normal model. The nodes lie on the element boundaries where adjacent elements are connected. Once meshing and contacts are defined the next process is to define boundaryconditions.The process of creating the mesh, elements, their respective nodes, and defining boundary conditions is termed "discretization"of the problem domain. After defining the boundary of the model, the loads to be applied are defined. Once the loads are defined(Figures :5&6) the problem is solved by incorporation of the material property (table-II) and the results can be reviewed.

Fundamentals of Dental Implant Biomechanics in FEA

Since the components in a dental implant-bone system is an extremely complex geometry, FEA has been viewed as the most suitable tool to mathematically, model it by numerous scholars[18].In the past 2 decades, finite element analysis (FEA) has become an increasingly useful tool for the prediction of the effects of stress on the implant and its surrounding bone[49].Implant dentistry would greatly profit if it were provided the means to predict how bone and implant components would behave considering each patient's unique jaw anatomy, quality of bone, amount of occlusal force exerted on the prosthesis, etc. Finite-element analysis, with all its inherent limitations, is a valuable instrument in pursuing that goal. The Finite element method has some distinct advantages over the other methods of stress analysis;

1- The technique is non-invasive
2- The tooth, the alveolar bone , implant can be simulated and when the material properties of these structures are assigned, it is the nearest that one can possibly get in simulating the oral environ ment in vitro.
3- The actual stress experienced at any point can be measured.
4- The actual displacement of the implant can be visualized graphically.
5- Reproducibility does not affect physical properties of the involved material and study can be repeated any number of time.

Recently, with the development of digital imaging techniques, more efficient methods are available for the development of anatomically accurate models. These include the application of specialized softwares for the direct transformation of 2D or 3D information in image data from CT or MRI, into FEA meshes. The automated inclusion of some material properties from measured bone density values is also possible. This will allow more precise modelling of the geometry of the bone-implant system [49].

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Table I: number of elements and nodes

STRAIGHT ABUTMENT			ANGLED ABUTMENT		
BONE	NODES	ELEMENTS	BONE	NODES	ELEMENTS
D1	30243	16820	D1	30180	16720
D2	39143	23383	D2	39564	21066
D3	38908	20878	D3	38338	20452
D4	38908	20878	D4	38338	20452

Table2: Material properties used in FEA study

Material	Youngs modulus (GPa)	Poisons ratio
Titanium abutment & implant	110	0.35
Dense treabecular bone (D1 D2 & D3)	1.37	0.3
Low density trabecular bone (D4 Bone)	1.10	0.3
Cortical bone	13.7	0.3

Figure:1 Maxilla Bone Model

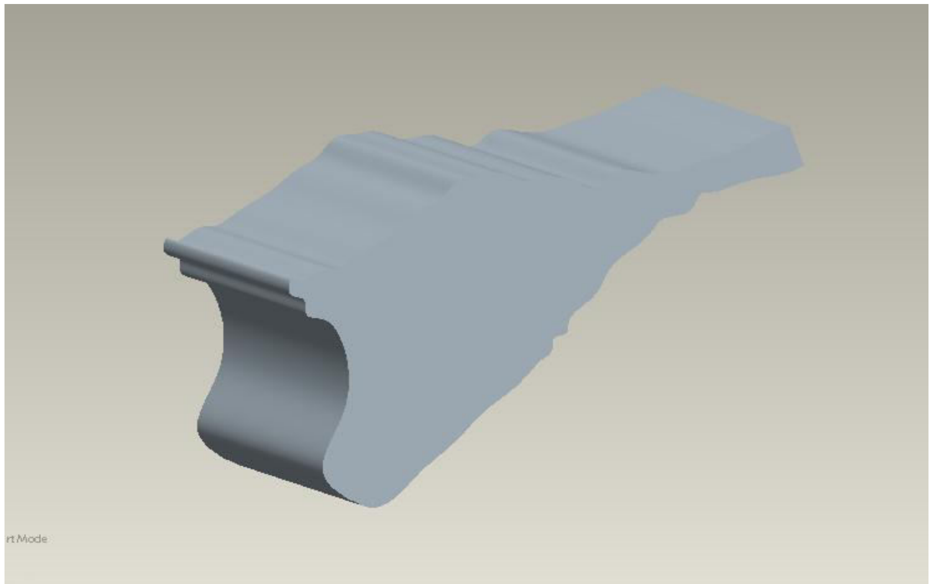


Figure: 2 Maxilla Bone With Implant and Angled Abutment

Figure :3 Maxilla Bone With Implant and Straight Abutment

Figure:4 Meshed model

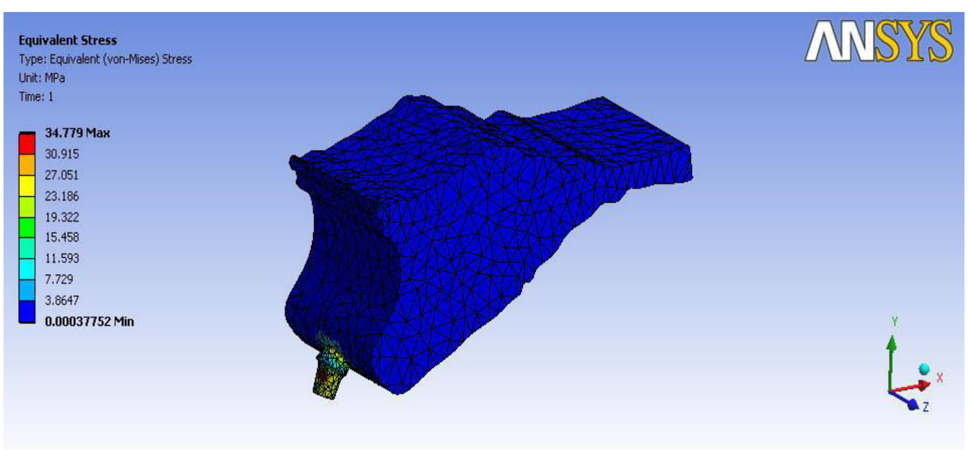


Figure: 5 Loading condition for implant and angled abutment

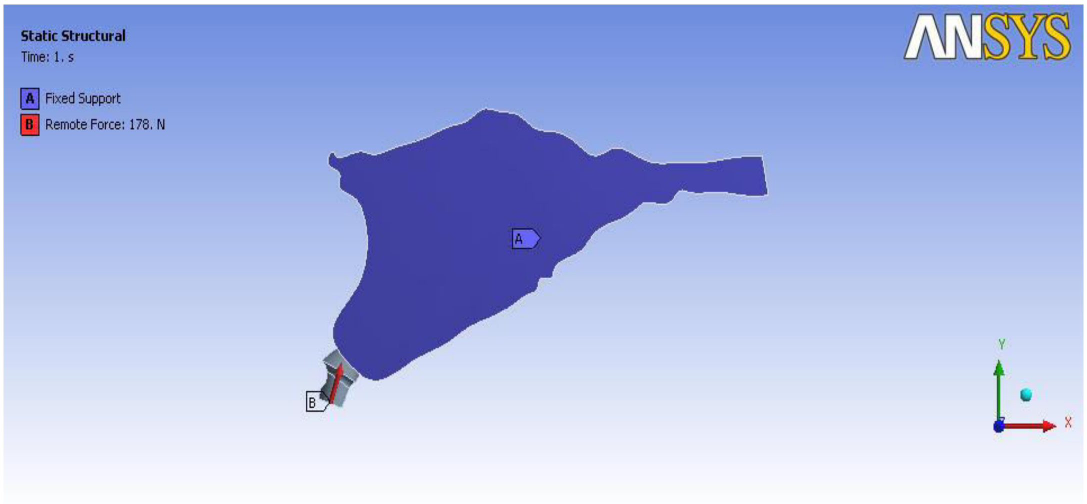
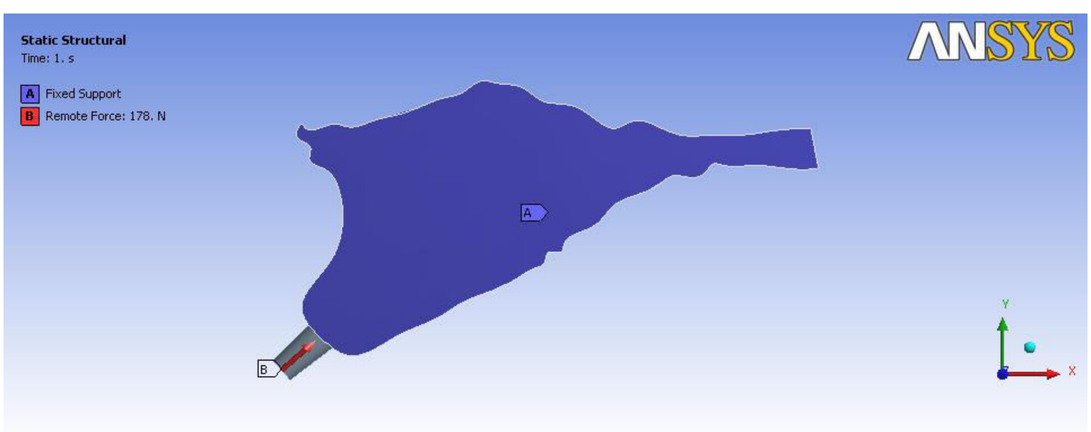


Figure: 6 Loading condition for implant and straight abutment



Results and Observations

RESULTS

Stress distribution was represented numerically and was colour coded. The von Mises stress for the straight abutment showed almost even distribution of stress in buccal and lingual side of both cortical and cancellous bone. The distribution of stresses changed considerably with the abutment angulation. As the angulation increased from 0^0 to $15^0$the concentration of von Mises stresses shifted to the cortical layer of bone on the facial side of fixture(Table III & IV). The von mises stress around M1and M2 was higher in cortical bone 3.66-20.832 than in cancellous bone 0.124 -2.0971.

In D1,D2,D3,&D4 bone qualities the highest von Mises stress values were obtained at the crestalregion of the implant(Figures- 7, 8, 9, 10). The von Mises stress on the buccal side of cortical bone in M1and M2 increased in magnitude as the bone quality differed from D1toD4. In all the four bone types the stress values in cortical and cancellous bone on the buccal side of M2 was found to be higher than the stress values on the buccal side of M1. The maximum von Mises stress of 20.832 was recorded in D4 cortical bone on the buccal side of M2(Figure-10) .

The stress values were found to be lower on the lingual side of implant with angled abutment in D2, D3, D4 bone types, when compared to the implant with straight abutment. The increase in stress in the buccalcortical bone when angled abutment as used was greatest for D4 bone (20.832) and least for D1 bone(13.022).

TABLE-3

The value of von mises stress for the models with straight abutment-MI

Bone quality	Buccal		Lingual	
	Cortical	Cancellous	Cortical	Cancellous
D1	4.0965		3.662	
D2	9.571	0.7787	7.551	1.068
D3	13.223	1.894	13.311	1.876
D4	15.444	1.1172	15.336	1.110

Figure – 11

Bar diagram showing Stress values with in Bone around implant M1

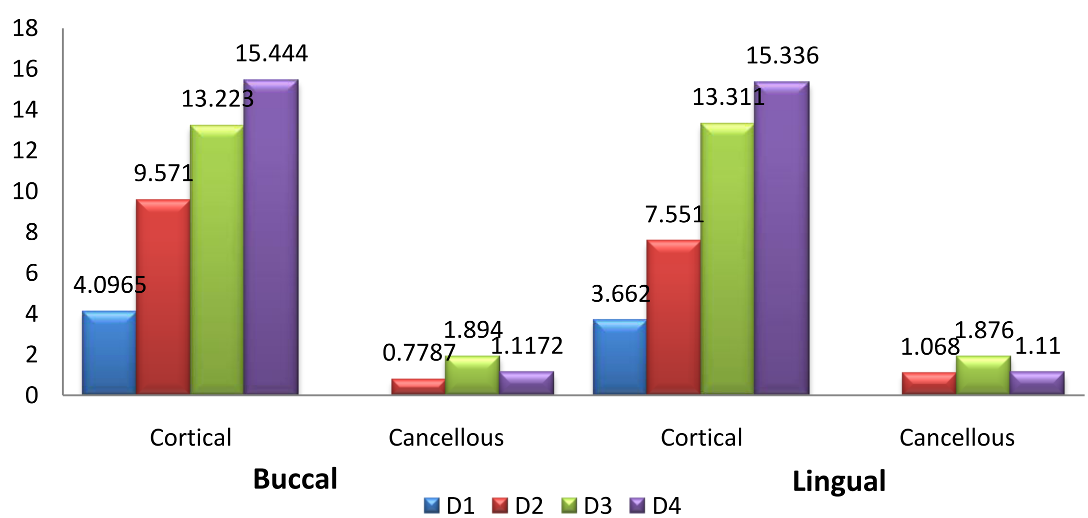


TABLE- 4

The value of Von Mises Stress for the models with angled abutmentsmM2

Bone quality	Buccal		Lingual	
	Cortical	Cancellous	Cortical	Cancellous
D1	13.022		4.798	
D2	13.999	1.6299	2.563	0.2360
D3	19.261	2.0971	2.538	0.1599
D4	20.832	1.856	2.138	0.1242

Figure – 12

Bar diagram showing Stress values with in Bone around implant M2

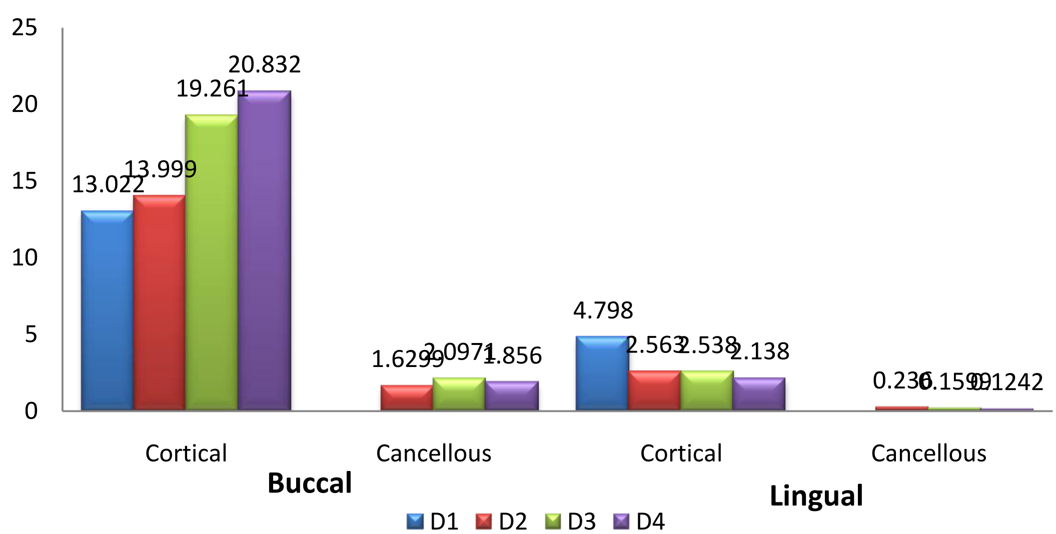
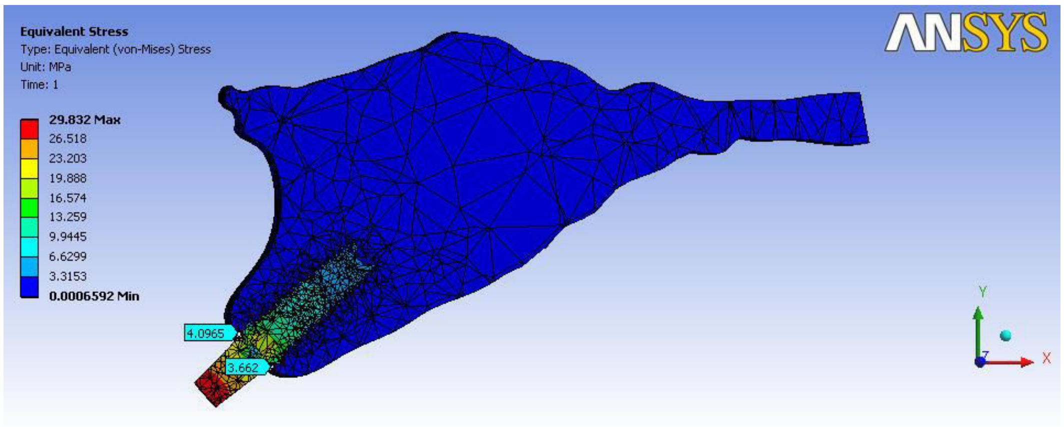


Figure:7 D1-STRAIGHT ABUTMENT



D2 STRAIGHT ABUTMENT

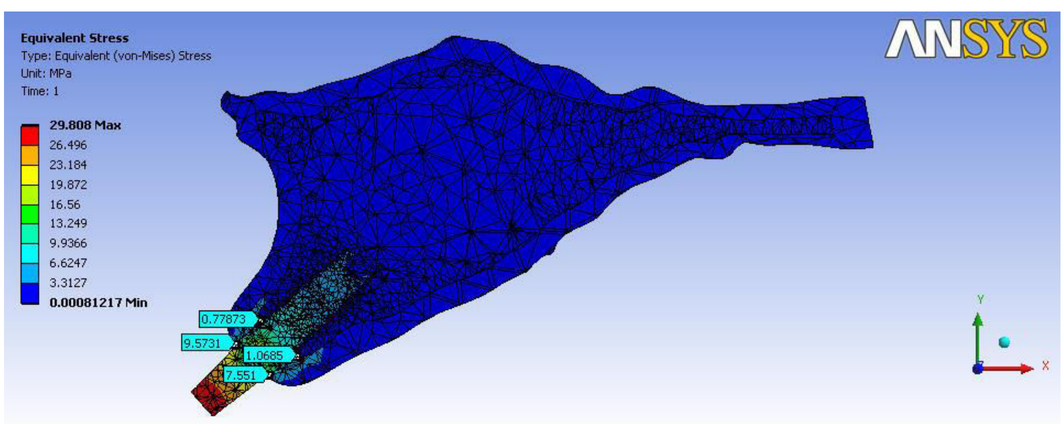
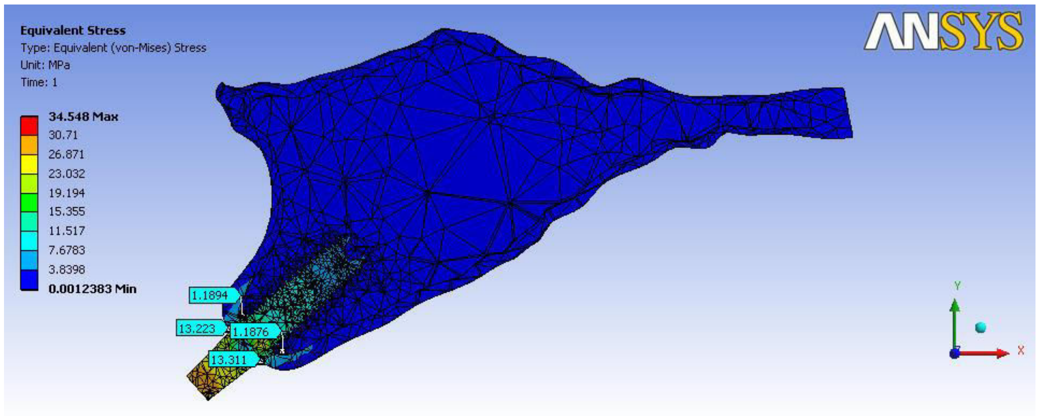


Figure:8 D3 STRAIGHT ABUTMENT



D4 STRAIGHT ABUTMENT

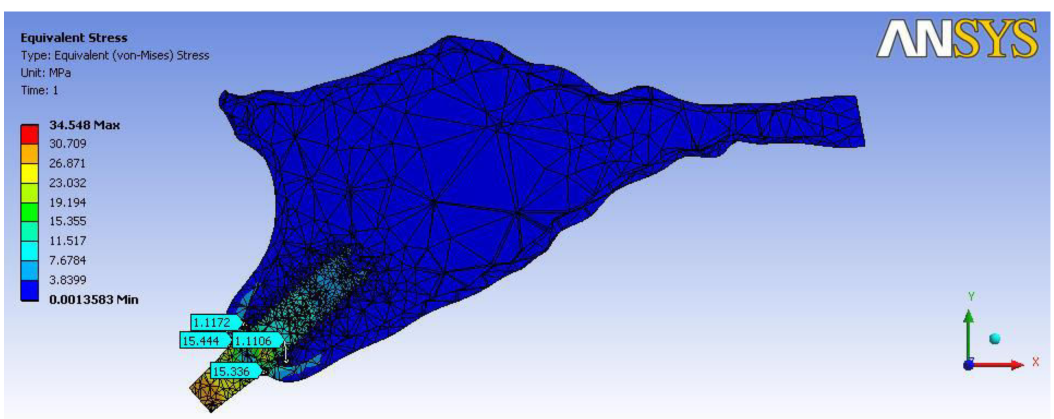
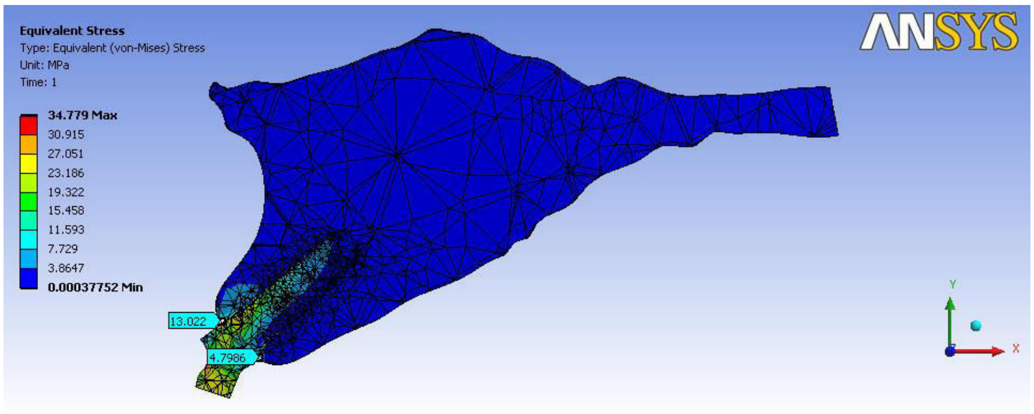


Figure:9 D1 ANGLED ABUTMENT



D2 ANGLED ABUTMENT

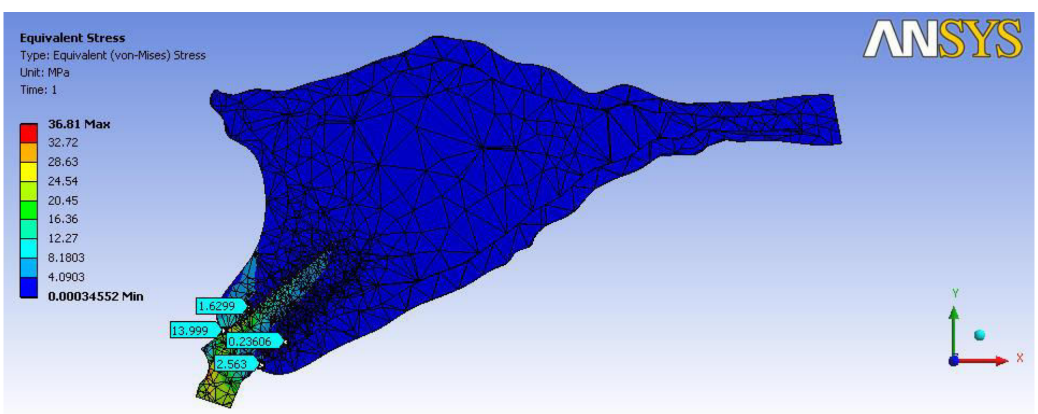
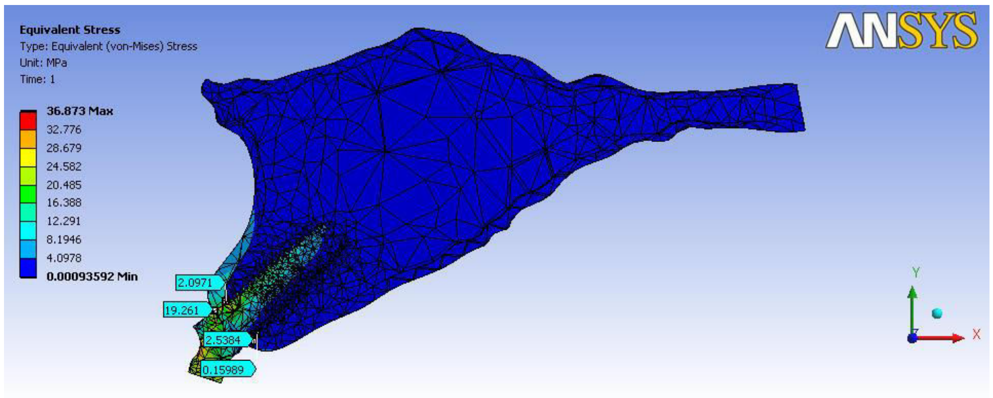
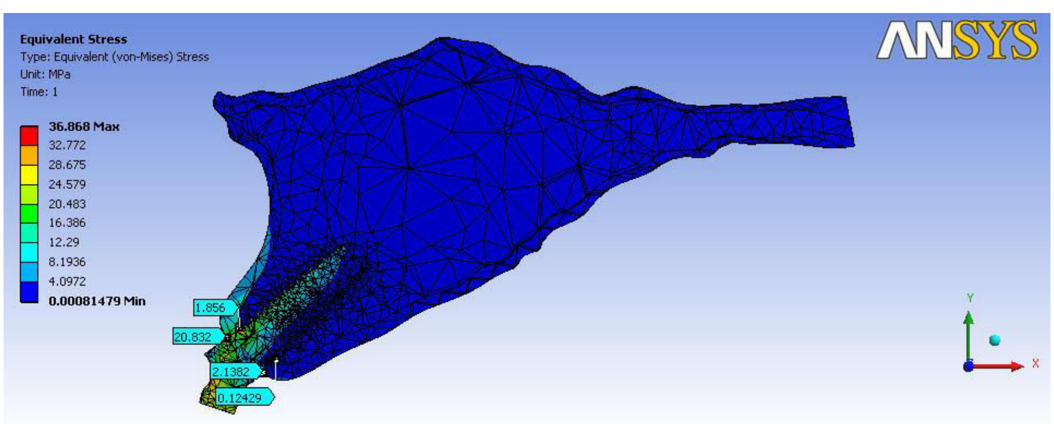


Figure:10 D3 ANGLED ABUTMENT



D4 ANGLED ABUTMENT



Discussion

DISCUSSION

The pattern of bone loss cannot be accurately predicted when teeth are lost in the anterior maxilla [1].Lower survival rates were observed for implants placed in the anterior maxilla than the anterior mandible[4.] Lack of bone volume is more common in the anterior maxilla. The long term prognosis for implants inthe maxilla is less secure than that of the edentulous mandible.

Following tooth extraction inthe anterior part of the maxilla horizontal bone resorption is almost twice as pronounced as vertical resorption[30] . This change in bone morphology often dictates placement of implants with the long axis in different and exaggerated angulations. The implant alignment is corrected at the time of restoration with the use of angled abutment. A variety of preangled abutments are available at specified divergence angles. Additionally, custom angled abutments may be cast to the profile necessary for an acceptable prosthetic outcome .

Studies on the biomechanical behavior of implants have concluded that the major concentration of stresses at the implant bone interface usually occurs at the crestal bone level[8,29, 35, 36, 40] .

Crestal bone loss and early implant failure after loading results most often from excess stress at the implant bone interface. This phenomenon is explained by the evaluation offinite element analysis of stress contours in the bone[5, 7,8,12, 33, 36,40,45].In the present study also the maximum von Mises stress values were found at the crestal bone in all the four bone qualities .

The anteriorteeth were subjected to maximum compressive stress duringincising and the force would be directed along the long axis of the tooth. In implant with straight abutment the force is directed along the long axis of the abutment and this results in the even distribution of stresses on the buccal and lingual side in all the four bone qualities.

In angled abutment the force will be directed to the area of bone opposite to that of crown inclination . In the present study the results shows that the stress values on the buccal bone was found to be higher when the abutment was inclined 15degree palatally. This leads to the inference that if a case is planned for angled abutment, sufficient thickness of bone should be available on the site opposite to that of abutment inclination to withstand the extra stresses.

The stress values around M1and M2 were found to be more at the cortical bone region than in cancellousbone. This is likely due to the difference in the modulus of elasticity in cortical and cancellous bone.

Cortical bone having a higher modulus of elasticity is more resistant to deformation and will bear more load than cancellous bone. A finite element analysis study by Jose Henrique Rubo[35]showed that stresses tended to be concentrated at the cortical bone around the neck of the implant closest to the load, whereas stresses in cancellous bone were considered low. The mechanical stress distribution occurs primarily where bone is in contact with the implant. The density of bone is related directly to the amount of implant to bone contact. The percentage of bone contact is significantly greater in cortical bone than cancellous bone.

The increase in stress values from D1 to D4 cortical bone may be due to the fact that D1 bone is comprised of entire cortical bone andwas able to distribute the stress evenly, whereas in D4 bone there was only a thin layer of cortical bone, stresses were principally concentrated in the compact bone, so the stress concentration per area will be more.

Although von Mises stress increased in straight abutment as the bone quality changed from D1 to D4, it was more noticeable under the loading side of the angulated abutments.

There is more increase in the stress concentration in the cervical zone of the angled abutment when compared with the straight ones.Due to the unfavorable loading direction that angled abutments have, it is important to understand the stresses transferred through various abutment angulations to the surrounding bone, through which we can prevent less than ideal stress transfer conditions[16,2].

Implant dentistry would greatly benefit if it were provided the means to predict how bone and implant components would behave considering each patient's unique jaw anatomy, quality of bone, amount of occlusal force exerted on the prosthesis, angulation of abutment etc. Finite element analysis, with all its inherent limitations, is a valuable instrument in pursuing that goal[18].

Other types of failures related to angled abutments in reviewed articles included fracture of the occlusal material[14],fracture in parts of the Framework[14] , loosening or fracture of abutment screws[20]and loss of osseointegration[15] .

Most of the articles claiming high success/survival rates did not take abutment screw loosening, occlusal material, or framework fracture into account in calculating the success/survival rates. These complicationsmight not eventually lead to implant failure, but can still be major concerns from a biomechanical point of view.

In a study Clelland and colleagues[7] , used a three dimensional finite element model of the maxilla and confirmed that stresses and strains became larger as abutment angles increased. In another study by Ding xi and colleagues [29]on the influence of various angled abutments on the distribution of the stress and strain in the implant-bone interface, revealed that von Mises stress occurred predominantly in the cortical bone layer on the neck of implants.

Results of finite element analysis done by Kao and colleagues [36]on the influence of abutment angulation on micromotion level for immediately loaded dental implants showed that most of the stresses were concentrated within the cortical bone around the neck of the implants. The authors concluded that abutment angulation up to 25 degrees can increase the stress in the periimplant bone by 18% and the micromotion level by 30%.

Lin and colleagues [40] who conducted an analysis of stress on single implants, also noted that the strains on the implant and cortical bone was higher for an angled abutment of 20° than that of straight abutments and that bone strain increased as bone density decreased.

The high stress concentration found around the coronal zone of the implant should be considered. Clinical studies show that bone resorption occurs around the coronal zone of the implant[39].

In finite element analysis studies, the assumptions made regarding the geometry, mechanical properties of the materials, and loads and constraints applied to the model have a key role in the accuracy of the experiment[49]. Clelland et al[7]created a 3-dimensional model of the anterior maxilla with a 1.5- and 3.0-mm-thick cortical layer with isotropic characteristics, which does not represent type 3 bone with a thin cortical layer.

In the current study, all of the bone for the D1 bone model was modelledas compact bone. Consequently the stress distribution was more uniform and von Mises stresses were of a lower magnitude in straight abutment in buccaland lingual side , whereas the von Mises stress was concentrated in more magnitude in buccal side of the angled abutment than the lingual side. So as angulation is increased from 0^0 to 15^0 the concentration of compressive stresses shifted to the cortical layer of bone on the facial side of the fixture.

For theD2 bone model, the elastic modulus of the central core of bone was reduced. Stresses were borne mainly by the compact bone, and the available volume of compact bone was less than D1 bone quality. It was almost equally distributed in both buccal and lingual side of D2 bone (9.573& 7.551), whereas in the case of angled abutment there was a prominent difference in readings of stress in both buccal and lingual (13.99 & 2.563).

In the D3 bone model, the thickness of the cortical shell was reduced. Stresses were principally concentrated in the compact bone, and again, the available volume of compact bone was less than for both D1 and D2 bone qualities. The von Mises stresses were higher than D1 and D2 bone qualities. This was more in angled abutment (19.261) compared to straight (13.223).

The D4 bone model had the same cortical bone configuration as for D3 bone quality; the only difference between these two models was in the elastic modulus specified for the central core of bone (table-II).The low-density trabecular bone was modeled for D4 bone quality. Stress concentrations in compact bone showed the same distribution as in the D3 bone model, but the von Mises stress values were greatest for D4 bone quality 20.832 for angled and 15.336 for straight abutments.

Although von Mises stress increased in straight abutment as the bone quality changed from D1 to D4 it was more noticeable under the loading side of the angulated abutments. There is more increase in the stress concentration in the cervical zone of the angled abutment when compared with the straight ones .

Conclusion

CONCLUSION

Stress values concentration areas decreased for cortical bone when straight abutments were placed over the implant, whereas more stress distributions were seen for cortical and cancellous bone with angled abutments placed over the implant. So the high stresses induced through preangled abutments at the cervical zone of the implant due to forces and moments could be a dominant factor that may aggravate the periimplant bone loss or may change the existing peri-implantitis direction. An alternative treatment plan, such as inserting the implant in perfect alignment, concomitant with autogenous bone graft and membrane should be considered to minimize the use of preangled abutments and to avoid the much higher stresses induced by them.

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